Development of a Concrete Parabolic Trough Collector

FIGURE 1. Pair of SCE with drive system in the middle

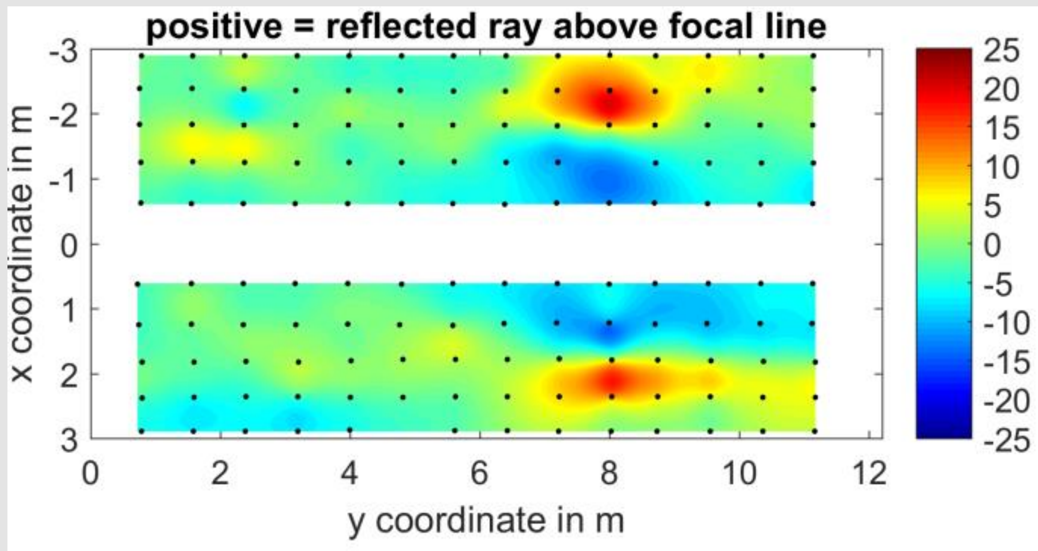

FIGURE 2. Results of slope deviation in mrad in x direction with corrected receiver position – positive values indicate a reflection of the rays above the focal line

Introduction

Current parabolic trough collector development mainly aims at cost reduction. Within the project ConSol the goal was to reduce material and production costs by using high-performance concrete for the parabola shell itself and also for part of the tracking system. A high amount of manufacturing at the power plant site (“mobile factory”) by delivery of the raw materials and semi-finished products is foreseen, adding value to the local content. Within the project a collector prototype consisting of an extraordinary thin concrete shell was realised based on FEM calculations. The shell is moved via a novel sickle-shaped hill with a newly developed drive system. The collector’s shape was measured by photogrammetry and its optical performance deduced. A part of the ConSol project was dedicated to the improvement of a PVD coated mirror multilayer system on electrochemical polished aluminium strip substrate. With these new layer systems the reflective properties could be increased significantly. Finally, the costs of the system was summarised and cost benchmarks with existing collector technology.

Design

A choice at the beginning of the project was the use of a high performance concrete with very high flexural tensile strength of 18.2 MPa for the parabola material and a high Young’s modulus. Thereby, a non-cracked state and low deformations should be ensured. By a distributed drive system a torsion body, which would be difficult to be poured in concrete, could be avoided. Two solar collector elements (SCE) are connected to one drive unit (FIGURE 1). The parabola rolls along a sickle-shaped hill. It is formed in a way that the centre of gravity of the upper construction remains on the same horizontal level while the trough is tracked. To avoid sliding of the trough on the hill, cog wheels at the side of the upper and lower hill are positioned.

The movement is transferred via chains from a small engine between the pair of SCE. A pipe connecting the drive system of each SCE pair secures a parallel movement of the entire row even if one of the engines fails. The thickness of the parabola was calculated via FEM. A thickness between 5.5 cm in the middle and 3.5cm at the edge of the parabola has been realised, which would resist typical wind and other loads. Because of safety reasons the concrete had to be reinforced with steel.

Development of mirrors based on aluminium coil

A part of the ConSol project was dedicated to the improvement of PVD coated mirror multilayer system on electrochemical polished aluminium strip substrate. This reflector material offers the advantage of flexibilty so that it can be applied to any geometry. The pretreated aluminium coils with a width of 1250 mm are coated on an industrial air-to-air PVD strip coater, ensuring a cost efficient mass production of the material.

The solar weighted, specular reflectance of a silver mirror on aluminium coil substrate could be strongly improved compared to similar materials previously commercially available (TABLE 1). The solar-weighted hemispherical reflectance could be raised to 96.4 % exceeding vlues of state of the art glass mirrors. The mirror has a slightly lower specularity of 0.947 which results in a specular reflectance (at 660 nm) of 92,3%.

Photogrammetry

The shape accuracy of the parabolic trough, the positioning of the receivers as well as structural deformations due to dead-load have been assessed by means of close range photogrammetry.

The height deviation of the mirror points in zenith position shows a considerable and systematic widening of the parabolic crossection: In comparison to the design parabola the concentrator shell is too high in the region of the vertex and to low towards the edges. This translates to large local and systematic slope deviations SDx that in turn lead to a large fraction of the incident sun light missing the receiver, resulting in a low intercept factor of only 46%. Height and slope deviations in y-direction are typically less critical for parabolic trough collectors. In the present case they were well within the tolerable range and thus not dealt with in detail here.

As the effective focal length of the concentrator is thus systematically increased compared to the design, this can be compensated by adjusting the receiver position. Optimum optical results are archieved by an upshift of the receiver by about 60 mm resulting in a focal length of 1780 mm instead of 1720 mm: The SCE intercept increases to 85.6% (FIGURE 2).

TABLE 1: Comparison of reflective properties

material	$\rho_{s,h}$([280,2500],8°,h)	$\rho_{\lambda,h}$(660nm,8°,h)	$\rho_{\lambda,s}$(660nm,15°,12.5mrad)
1mm glass mirror	0.956	0.965	0.965
4mm glass mirror	0.944	0.957	0.950
ConSol mirror system	0.964	0.975	0.923
Alumir mirror system	0.897	0.906	0.826

The widening of the concentrator shell may result from the impression taken during casting, creep, setting and shrinking processes during curing of the concrete as well as in the deformation due to own weight. The deformation analysis comparing measurement results in zenith and horizon position clearly indicates that the latter is an issue for the current prototype.

Cost analyses

As a part of cost benchmarking, a CSP plant with the size of Andasol 1 was evaluated. All plant components except the solar collector (solar collector assembly) are considered to be the same as Andasol plant (TABLE 2).

Thus the costs for a solar field of 510,000 m² collector aperture surface were determined. Reduced costs for economies of scale were included and the costs for the means of production were calculated in detail. The specific price per square meter is 261 €/m² compared to 242 €/m² for the Andasol power plants for completely installed solar fields including collectors, field piping, electrical engineering, control etc. . .

Studies on slimmer concrete structures have shown that it is possible to reduce the weight of the collector shell and rolling hills by approx. 50 %. This would reduce the material costs for these components from 76 €/m² to 38 €/m² and the specific collector field costs to 223 €/m².

The expected annual yields of a collector were determined based on the results of the photogrammetry of the two collector modules built. The calculations show that the LEC (Levelised Costs of Electricity) for a power plant with Andasol layout with the investments and the efficiency of the ConSol collector are around 21.93 €-ct/kWh. In comparison, the LEC of the Andasol reference power plant is 19.0 €-ct/kWh.

Component	Costs in €/m²
Foundations, sickles, cog wheels and parabola	87
Mirror and adhesive tape	19
Steel components	16
REPA	4
Tracking	23
Receivers	30 (680€/unit)

FABLE 2. Component costs

Project partners

German Aerospace Center
Solarlite CSP Technology GmbH
Stanecker Betonfertigteilwerk GmbH
Almeco GmbH
Pfeifer Seil- und Hebetechnik GmbH
Ruhr-Universität Bochum
Technische Universität Kaiserslautern

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DLR Deutsches Zentrum für Luft- und Raumfahrt

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